Characterizing the Significance of Power Plant Blowdown Pollution on Rivers

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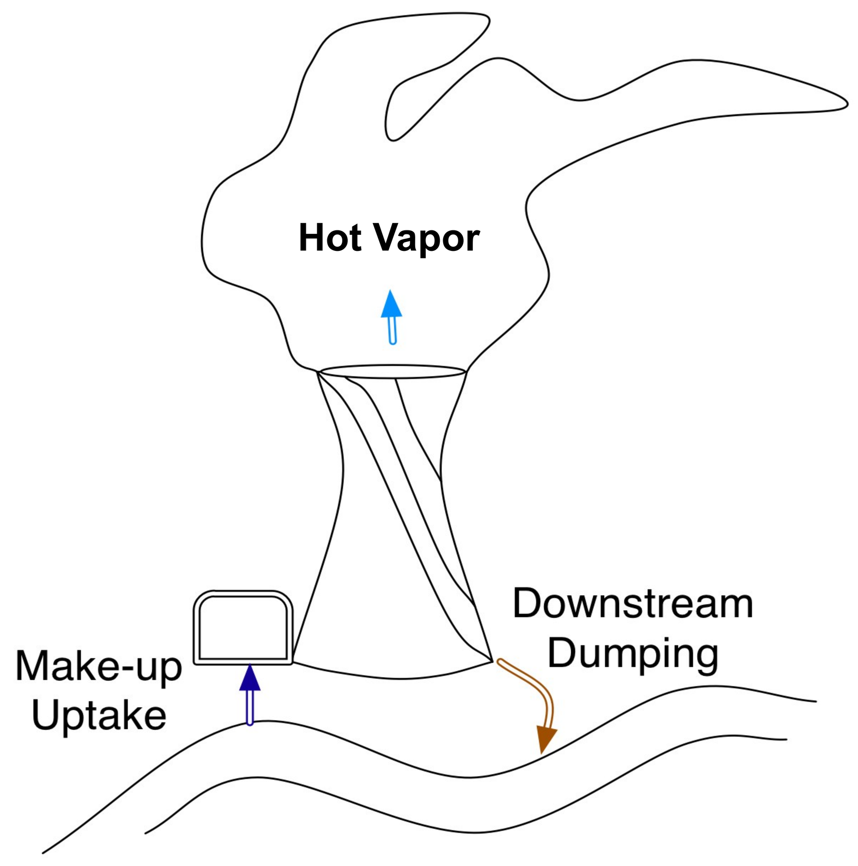
Objective

- Wet cooling towers dump waste heat
- Water from sources like rivers is used to cool the working fluid
- Some pure water is removed by air as water vapor
- Dissolved particulates in the circulating water remain behind and accumulate, called **blowdown pollution**
- Blowdown pollution is often dumped back into natural bodies of water
- Our objective: **relate blowdown generation to power production**
- Relates environmental cost to societal benefits



Validation

- Compared an instance of our model with data from several plants obtained by the United States Department of Energy
- All cooling towers run 4 cycles of concentration
- Change in temperature across the condenser is 25 degrees F
- Maximum wet bulb temperature is 75 degrees F
- Our cooling tower, in this instance, furthermore
  - Takes in river water at 290 K
  - Has a flow rate of 8,000 kg/s
  - Operating with the maximum wet bulb temperature

Cooling water losses in kg/s	GE Energy Radiant-Convective IGCC	Natural Gas Combined Cycle	Subcritical Pulverized Coal Plant	Our Model
Cooling tower blowdown	51.67	39.00	81.83	70.25
Cooling tower evaporation	155.3	117.0	245	210.7
Ratio of blowdown to evaporation	33%	33%	33%	33%

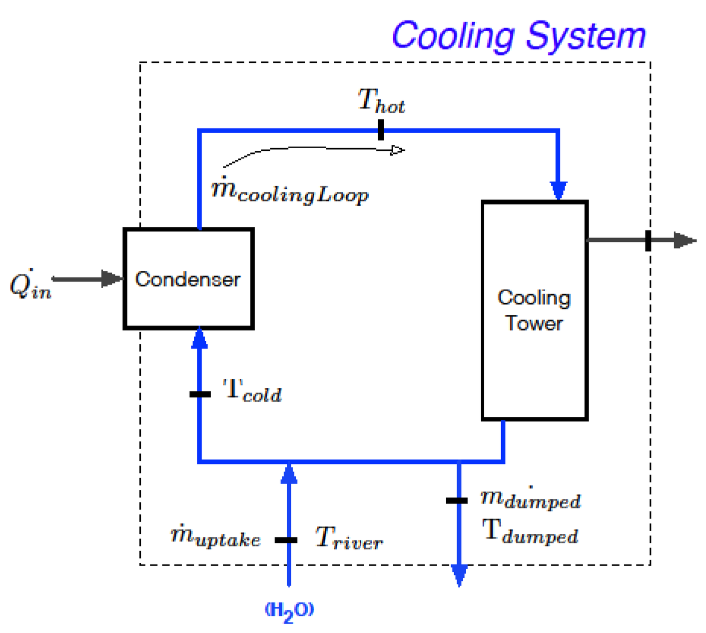
Modeling a Cooling Tower

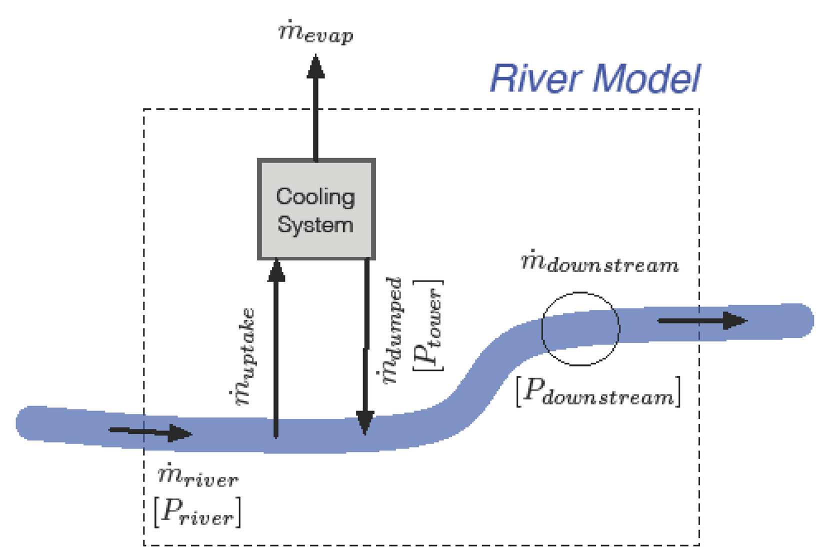
The Cooling System

- Condenser transfers waste heat from power plant to cooling loop
- Warmed river water circulates to a natural draft wet cooling tower
- Air carries away heat via pure water vapor
- Solids do not evaporate and remain in the loop
- A specified concentration of solids in the system is maintained for system health by dumping a potion of the working fluid back into the river
- Lost working fluid is replaced with more river water

The River Model

- Cooling system draws water from the river
- Cooling system returns less water to the river
- Concentration of particulates increases across the cooling system
- Results in a river with less water at a higher concentration of particulates





Our simplified cooling system model is a system of 6 coupled, nonlinear equations, where T_{cold}, T_{hot}, T_{dumped}, m_{uptake}, m_{dumped}, and m_{evap} are the six unknowns.

1) $$\mu = \frac{T_{hot} - T_{cold}}{T_{hot} - T_{wb}(\tau)}$$ Definition of cooling tower efficiency

2) $$T_{cold} = \frac{\dot{m}_{uptake} T_{river}(\tau) + T_{dumped}(\dot{m}_{coolingLoop} - \dot{m}_{evap} - \dot{m}_{dumped})}{\dot{m}_{coolingLoop}}$$ We find T_{cold} by taking a mass-weighted average of T_{river} and T_{dumped}

3) $$\dot{Q}_{in} = \frac{T_{hot} - T_{cold}}{C_p \dot{m}_{coolingLoop}}$$ Energy balance across condenser

4) $$\dot{m}_{evap} = \frac{m_{coolingLoop} C_p (T_{hot} - T_{dumped})}{H_v}$$ Energy balance across the cooling tower

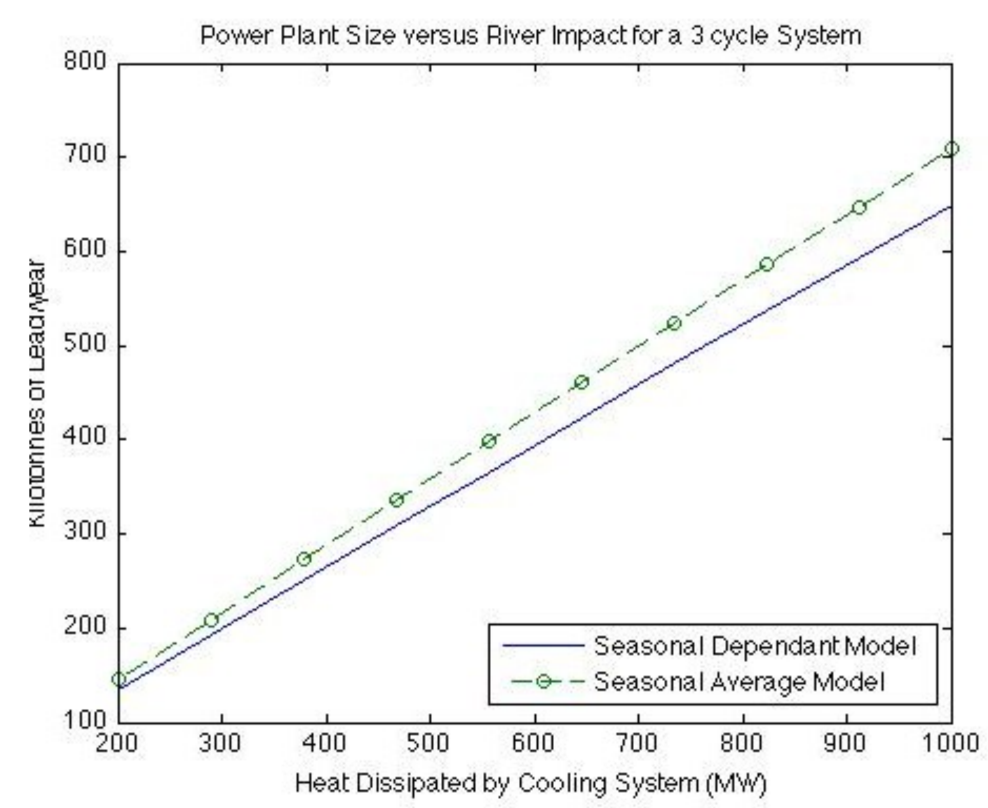
5) $$\dot{m}_{dumped} = \frac{\dot{m}_{evap}}{cycles - 1}$$ Conservation of particulate mass, where cycles is defined as: $cycles = \frac{[P_{tower}]}{[P_{river}]}$

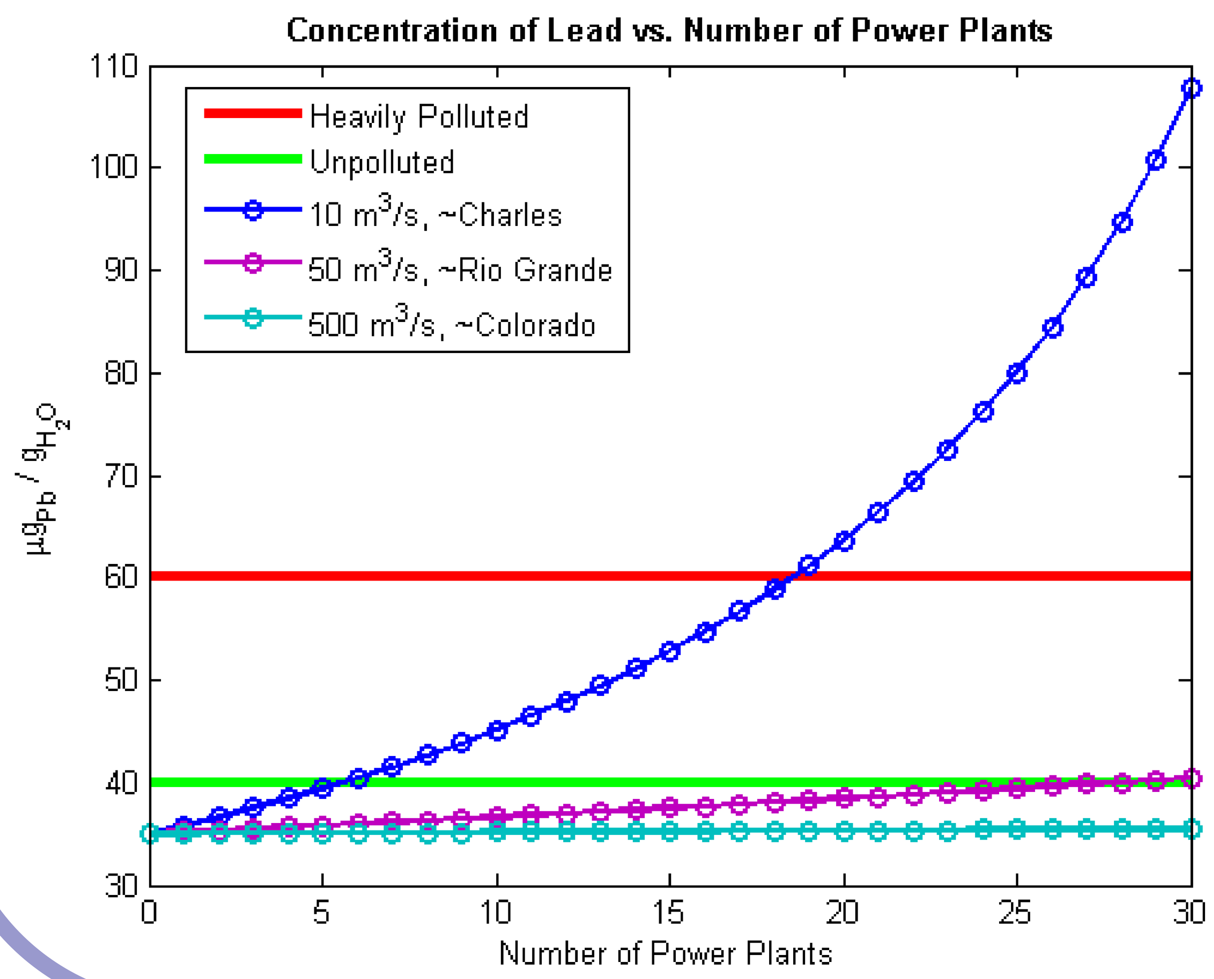
6) $$\dot{m}_{uptake} = \dot{m}_{evap} + \dot{m}_{dumped}$$ Conservation of fluid mass, assuming constant $m_{coolingLoop}$

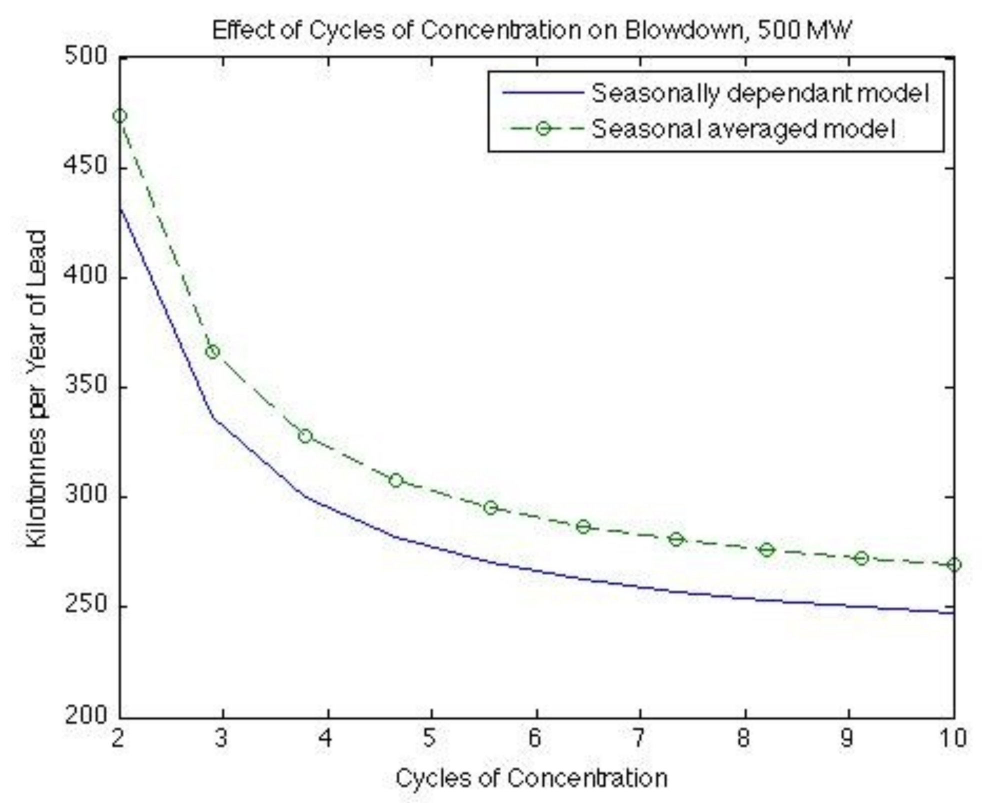
River Model: $$[P_{downstream}] = (\dot{m}_{river} - \dot{m}_{uptake})[P_{river}] + \dot{m}_{dumped}[P_{tower}]$$

Investigations: Seasonal effects, cycles of concentration, and number of plants

- Changes in season do affect the quantity of particulates dumped per year due to the nonlinear characteristics of the system
- Changing the cycles of concentration measurably affects the quantity of blowdown pollution dumped per year
- These effects are small in comparison to the effect of having multiple power plants along a single river.







Conclusions

- There is a linear relationship between blowdown production and heat dissipated. Slope is mostly dependent on the cycles of concentration of the cooling system: $[P_{tower}]/[P_{river}]$.
- The system model is nonlinear. Utilizing time-dependent T_{wb} and T_{river} variables reveals an approximately 8% error in comparison to assuming constant conditions year-round due to the system's nonlinearity.
- Changes in power plant operations, specifically cycles of concentration, have a measureable effect on the quantity of pollution generated by a single plant.
- However, that change is small in comparison with the effect of having several plants along one river.

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